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Title:

POWER MANAGEMENT CONTROL AND CONTROLLING MEMORY REFRESH  
OPERATIONS

Inventor:

Dean A. Klein

Thomas J. D'Amico  
DICKSTEIN SHAPIRO MORIN &  
OSHINSKY LLP  
2101 L Street NW  
Washington, DC 20037-1526  
(202) 828-2232

## **POWER MANAGEMENT CONTROL AND CONTROLLING MEMORY REFRESH OPERATIONS**

### **FIELD OF THE INVENTION**

[0001] The present invention relates generally to memory, and more particularly controlling memory refresh operations in memory.

### **BACKGROUND OF THE INVENTION**

[0002] An essential data processing component is memory, such as a random access memory (RAM). RAM allows the user to execute both read and write operations on memory cells. Typically, semiconductor RAM devices are volatile, in that stored data is lost once the power source is disconnected or removed. Typical examples of RAM devices include dynamic random access memory (DRAM), synchronous dynamic random access memory (SDRAM) and static random access memory (SRAM).

[0003] In recent years, the memory capacity, i.e., the number and density of memory cells in memory devices have been increasing. Accordingly, the size of each cell (including storage capacitor size) has been shrinking, which also shortens the cell's data holding time. Typically, each row in a memory device receives a stabilizing refresh command in the conventional standardized cycle, about every 64 milliseconds. However, with increasing cell number and density, it is becoming more and more difficult to stabilize all memory cells at least once within the stabilizing cycle, e.g., it requires more power as well as a significant portion of the available bandwidth.

[0004] DRAMS and SDRAMs are volatile in the sense that the stored data, typically in the form of charged and discharged capacitors contained in memory cells arranged in a large array, will dissipate the charge after a relatively short period of time

because of a charge's natural tendency to distribute itself into a lower energy state. DRAM is particularly volatile in that each cell should be stabilized, i.e., refreshed, typically every 64 milliseconds, in order to retain information stored on its memory cells.

[0005] Recently, studies have been conducted on the use of chalcogenide glasses as ionic conductors which can be used to build non-volatile memory cells. One such non-volatile memory device, which uses chalcogenide glass to form non-volatile memory cells is known as a programmable conductor RAM (PCRAM). See, for example, U.S. Patent publication number 2002/0123248.

[0006] Although referred to as non-volatile memory elements, the PCRAM memory elements are more accurately nearly non-volatile memory ("NNV memory"). The NNV memory elements do require periodic refreshing, although the refreshing operations occur significantly more infrequently than refresh operations in standard volatile DRAM or SDRAM memory elements. Once a refreshing operation is complete, a memory device incorporating the NNV memory elements can be placed into an extremely low power state until either the system is returned to a normal operating state or until another refreshing operation is required.

[0007] A memory system may comprise many memory devices. Although the amount of time allotted to a refresh operation is conventionally pre-determined and therefore static, each memory device may require a different amount of time to complete the refresh operation. The difference in the amount of time required for a refresh operation is caused by a variety of factors. For example, the difference may stem from inaccuracies and inefficiencies in the performance of a refresh operation, or it may be caused by differences in memory architectures of a memory device. Furthermore, the time a device requires for a refresh operation may vary due to various factors, such as amount of memory that needs refreshing. For example, if a refresh operation is

performed as a burst operation, with all cells in all devices being refreshed in a series of sequential operations, even a small variation of individual cell refresh times accumulates into significant differences in the refresh times for the entire device containing the individual cells.

[0008] The time allotted to perform a refresh operation is generally set at the maximum amount of time the devices could require to perform the refresh operation. Otherwise, if the time period is set too short, some devices may not complete the refresh operation before the time period expires. Thus, there is wasted time when the amount of time required for a refresh operation is shorter than the pre-determined, allotted refresh operation time.

[0009] Similarly, the frequency of refreshing a memory system is conventionally static and pre-determined. However, many factors affect the minimum frequency necessary to ensure retention of stored information. For example, in a memory system that includes NNV memory elements, ambient temperature affects the volatility of the NNV memory elements--the ambient temperature affects the ability of the memory elements to retain a stored state.

[0010] It would be advantageous to have memory refresh techniques that reduce wasted time.

## BRIEF SUMMARY OF THE INVENTION

[0011] Exemplary embodiments of the present invention provide memory refresh and power management circuitry whose operation can be affected by dynamic factors. The circuitry can also reduce time delays in refresh operations. The various embodiments of the invention may be used with any memory requiring refresh.

[0012] Rather than allotting a pre-determined amount of time to complete the refresh operation, the memory refresh circuitry of an exemplary embodiment provides a refresh complete signal indicating when a burst self-refresh operation is complete. In a system with multiple memory devices, the refresh complete signals from the devices are combined. A power management circuit receives the refresh complete signal when the refresh operation has been completed.

[0013] In another exemplary embodiment of the invention, a memory system monitors a condition, such as ambient or internal temperature, and initiates refresh operations based on the temperature. The system can include a circuit monitoring the ambient and internal temperatures, and the refresh circuitry can initiate a refresh operation in response. The refresh circuitry initiates a refresh operation based on either established set temperature points or the integration of temperature.

[0014] Another exemplary embodiment of the invention is a combination of the embodiments described above. For example in this exemplary embodiment, a memory system provides memory refresh circuitry whose operation can be affected by dynamic factors and monitors a condition, such as ambient or internal temperature, and initiates refresh operations based on the temperature.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0015] These and other features and advantages of the invention will be more readily understood from the following detailed description of the invention which is provided in connection with the accompanying drawings, in which:

[0016] Fig. 1 depicts a block diagram of a memory system in accordance with an exemplary embodiment of the invention;

[0017] Fig. 2 shows a block diagram of a memory device in Fig. 1 in greater detail in accordance with an exemplary embodiment of the invention;

[0018] Fig. 3 shows a block diagram of the refresh counter of Fig. 2 in greater detail;

[0019] Fig. 4 shows a block diagram of the power management controller of Fig. 1 in greater detail in accordance with an exemplary embodiment of the invention;

[0020] Fig. 5 shows a block diagram of the power management controller of Fig. 1 in greater detail in accordance with another exemplary embodiment of the invention;

[0021] Fig. 6 shows a memory system as in Figs. 1-5 integrated on a semiconductor chip; and

[0022] Fig. 7 shows a memory system as in Figs. 1-5 integrated in a processing system.

#### DETAILED DESCRIPTION OF THE INVENTION

[0023] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those of ordinary skill in the art to make and use the invention, and it is to be understood that structural, logical or procedural changes may be made to the specific embodiments disclosed without departing from the spirit and scope of the present invention.

[0024] Fig. 1 depicts a memory system 510 in accordance with an exemplary embodiment of the invention. Memory system 510 includes a memory controller 520, memory devices 530, memory bus 540, power management controller 550, resistor 552, system controller 559, logic power supply 553, and memory power supply 555.

Although shown with four (4) memory devices 530, memory system 510 can have any number of memory devices 530. Memory systems with larger numbers of memory devices 530, may require additional circuit, for example, the system may require multiple memory buses 540 and memory power supplies 555. A memory device 530 is described in greater detail below. The memory controller 520 is coupled to the memory devices 530 through memory bus 540. Through the memory bus 540, the memory controller 520 exchanges data and control signals with memory devices 530. For example, memory controller 520 provides a command indicating that data is to be written to a certain location of a particular memory device 530. Further, memory controller 520 also provides a command indicating when a memory device 530 should perform a refresh operation, or enter a standby self-refresh mode of operation. Data and other signals from memory devices 530 are provided to different parts of the memory system 510 through memory bus 540. Although the memory controller 520 is depicted as being incorporated into system controller 559, other implementations of the memory controller 520 and system controller 559 are possible.

[0025] As seen in Fig. 1, memory devices 530 are coupled to a memory power supply 555 (Vdd3) through line 557. Power supply 555 provides power to each memory device 530. Although shown as a single line in Fig. 1, line 557 is representative of several power lines that may couple the power supply 555 to a memory device 530. In implementation, multiple lines 557 are used for different power plane paths, where each line 557 is associated with a respective power plane. There may be a single or multiple power plane paths to each memory device 530.

[0026] Power management circuit 550 is coupled to memory power supply 555 and controls the supply voltage and therefore power provided to each memory device 530. Further, power management circuit 550 controls the power supplied to each memory device 530 on each power plane through each line 557. Power

management circuit 550 is coupled to and exchanges control signals with system controller 559/memory controller 520 and other system components through communications bus 560. Power management circuit 550 is discussed in greater detail below.

[0027] The power management circuit 550 is coupled to memory devices 530 through line 551 to each memory device 530. The pullup resistor 552 is also coupled to line 551 and line 557. Through line 551 power management circuit 550 receives a “refresh complete” signal from the memory devices 530 indicating that the memory devices 530 have completed a burst self-refresh operation. The refresh complete signal is advantageous, especially for NNV memory devices, because it allows for improved refresh operations, as described below. In an exemplary embodiment, line 551 carries a signal to power management circuit 550 indicating first and second states. In the first state, the signal carried on line 551 indicates to the power management circuit 550 that the burst self-refresh operation is under way. In a second state, the signal carried on line 551 indicates to the power management circuit 550 that the burst self-refresh operation is no longer under way, i.e., the burst self-refresh operation is completed.

[0028] In one embodiment of the invention, described below in relation to Fig. 1, the signal carried on line 553 is either at a supplied voltage level Vdd3 or the signal is at or near signal ground. The Refresh Complete outputs of all of the memory devices 530 on lines 551 are in effect logically ORed to provide a signal on line 551 indicating whether any of memory devices 530 is currently performing burst self-refresh, a configuration referred to as “wired-OR” or “dynamic OR.” Each memory device 530 can selectively couple line 551 to signal ground thus pulling it down from Vdd3. If any of the memory devices 530 couples line 551 to signal ground, then the signal on line 551 received by the power management circuit 550 is at or near signal

ground, indicating that a refresh operation is currently underway. If none of the memory devices 530 couple line 551 to ground, resistor 552 pulls down the refresh complete line 551 to the voltage on Vdd3 and the signal on line 551 received by the power management circuit 550 will be approximately Vdd3, indicating that all memory devices 530 have completed their burst self-refresh operation.

[0029] Fig. 2 depicts a portion of the memory device 530 of Fig. 1 in greater detail. Memory device 530 includes a control logic circuit 610, a memory array 620, an address multiplexer 630 and a refresh counter 605. Although shown with only one representative memory array 620, memory device 530 can include any number of memory arrays 620. Although shown with representative elements, memory device 530 may include additional memory or logic circuits not shown or described. Control logic circuit 610 controls access to the memory array(s) 620, and more specifically to the storage elements of the memory array 620. Although not shown, control logic 610 receives control signals from memory controller 520 (Fig. 1), which indicate the memory operation to occur, e.g., a read, write, or refresh operation. Further, the control logic 610 receives control signals from refresh counter 605 during a self-refresh or burst self-refresh operation. Further, the memory controller 520 (Fig. 1) provides a desired memory address to the memory device 530 (Fig. 2) which in turn is provided through multiplexer 630 to the memory array 620 to enable and control access to desired memory element(s) of the memory array 620. The memory address provided by the memory controller 520 is either multiplexed or un-multiplexed. If the address is multiplexed, it may be multiplexed with itself and/or with other signal lines, including, but not limited to, the data lines of the device as is conventionally known.

[0030] Control logic 610 provides a signal to the address multiplexer 630 to indicate the source of the inputted address that is provided to access a row in the memory array 620. For example, in a first, standard operational mode, the address

multiplexer 630 provides row addresses received from an outside circuit, e.g., the memory controller 520 (Fig. 1), to the memory array 620. In a second, refresh operation mode, the address multiplexer 630 provides row addresses received from the refresh counter 605 to the memory array 620. During the refresh operation, control logic 610 also provides signals to sense/refresh components of memory array 620 so that the value stored in a complete row of addressed memory elements is sensed and refreshed. Column addresses and column decoding are not shown or described with respect to Fig. 2, but are well known by those with skill in the art.

[0031] Refresh counter 605 (Fig. 2) controls the operation of its associated memory device 530 by providing a single address during a single self-refresh cycle or a series of addresses during a burst self-refresh operation. The addresses can be obtained by incrementing the refresh counter 605 at the completion of a refresh cycle to the memory array 620. The control logic circuit 610 may receive commands from the memory controller 520 (Fig. 1) indicating that a refresh operation should begin. These commanded refresh cycles may occur as in standard dynamic random access memory (DRAM) devices that are currently available. In a preferred embodiment of the invention, a burst self-refresh operation is included, which allows the entire memory array to be refreshed by a single command. A value of the refresh circuit 605 corresponds to an address in the memory array 620. For a commanded burst self-refresh operation, the refresh counter 605 is automatically reset to a value corresponding to the first row in a memory array 620, which is then refreshed. The value in the refresh counter 605 is incremented for each refresh of a row in the memory array 620 until the maximum value of the refresh counter 605 is reached. When the value of the refresh counter 605 is the maximum value then all of addresses of the memory array 620 will have been refreshed.

[0032] The automatic burst self-refresh operation is initiated by the control logic 610 as it senses certain conditions. These conditions may include, for example, time or temperature factors. For example, the condition of all inputs to the control logic 610 being held near signal ground would indicate to the control logic 610 the condition for an automatic burst self-refresh. During a burst self-refresh, refresh counter 605 is initially reset and will pull the signal on line 551 to ground. Following the refresh of each row of the memory array 620 the refresh counter 605 is incremented. The value of refresh counter 605 is provided as a row address to the address multiplexer 630 to access a row of the memory array 620 that is to be refreshed. For example, in operation, the refresh counter 605 first provides an address corresponding to the first row of the memory array 620 to the address multiplexer 630. After each row of the memory array 620 has been refreshed, the refresh counter 605 provides a new address corresponding to the next row of the memory array 620. When the memory array 620 has completed a refresh operation, e.g., all the elements of the memory array 620 have been refreshed, the refresh counter 605 will overflow, indicated by the release of signal on line 551, allowing it to return to Vdd3 if all other memory devices 530 have completed the refresh operation. This provides a signal to the power management circuit 550 (Fig. 1) indicating that the refresh operation is complete in all of the memory devices 530.

[0033] Fig. 3 depicts an implementation of the refresh counter 605 of Fig. 2 in greater detail. Refresh counter 605 includes an address and control counter circuit 695 and a refresh complete circuit 615. Address and control counter circuit 695 is coupled to the refresh complete circuit 615, the control logic circuit 610 (Fig. 2), and the address multiplexer 630 (Fig. 2) and also receives a clock signal. As is conventionally known, address and control circuit 695 provides and receives control signals from control logic 610 including a reset signal as shown, and provides address

signals (used for a refresh operation) to address multiplexer 630. Address and control circuit 695 provides a signal to the refresh complete circuit 615 indicating the status of the burst self-refresh operation. Address and control circuit 695 can therefore be implemented as a conventional counter or other suitable circuitry that can reset a count to zero, provide the count as an address, increment the count to the next address in response to a clock signal, and provide a signal on line 616 when the count reaches a maximum address value.

[0034] In an exemplary embodiment of the present invention, refresh complete circuit 615 includes a switch 617, e.g., a transistor, where the source region of the transistor is coupled to signal ground through line 618. The drain region of switch 617 is coupled to line 551. When transistor switch 617 is closed, or turned on, line 551, is coupled to signal ground through line 618. When switch 617 is open, line 551 is isolated from signal ground through line 618.

[0035] Line 616 can control switch 617 based on the value in a counter 696 in circuit 695. For example, line 616 indicates when the maximum value of the N-bit refresh counter 696 has been reached, i.e., when all of the addresses have been refreshed. In a preferred embodiment, when a burst self-refresh operation is underway in the memory device 530, the flip-flop 697 output Q will be off, and output Q\* will be on, and line 616 can close switch 617, coupling line 553 to ground. When the burst self-refresh operation has been completed in the memory device 530, as indicated by the maximum value being reached in the counter 696, the flip-flop 697 output Q will be on, and output Q\* will be off, and line 616 can open switch 617, not coupling line 553 to ground. Thus, memory device 530 provides a signal indicating whether its burst self-refresh operation has been completed by either coupling line 553 to ground or not coupling line 553 to ground. In one embodiment, refresh complete circuit 615

is an open drain comprised of an N-channel MOSFET whose source is tied to ground, e.g., VSS, and whose drain is tied to line 553 (Fig. 1) through line 551.

[0036] Fig. 4 shows an implementation of the power management controller 550 of Fig. 1 in greater detail. Power management controller 550 includes a microcontroller 680, bus 640, I/O ports 650, ROM 660, RAM 670, and inter IC (I<sup>2</sup>C) interface 690. Microcontroller 680 controls the operation of the power management controller 550 based on predetermined, preprogrammed criteria. Bus 640 couples I/O ports 650, ROM 660, RAM 670, and inter IC (I<sup>2</sup>C) interface 690 enabling these devices to exchange data and control signals. I/O ports 650 provide input and output connections to other devices and signals. For example, an output is coupled to a memory power plane controller (not shown) within the power supply 555 (Fig. 1) to enable the power management controller 550 to control the supply voltage provided to a memory device 530. If a memory system 510 has more than one memory power plane, the power management controller 550 is coupled to the memory power plane controller for each power plane within the power supply 555.

[0037] As seen in Fig. 4, the power management controller 550 includes storage areas ROM 660 and RAM 620. Further, the power management controller 550 includes an inter IC (I<sup>2</sup>C) interface 690 to permit coupling the power management controller 550 to another IC bus (or busses). Most often such a bus will allow communication with a main system processor.

[0038] A burst self-refresh operation of a NNV memory device(s) 530 may be initiated during a time when the system is in a standby, power-saving mode. The burst self-refresh capability allows most of the memory system to remain in a power-down state while the burst self-refresh operation occurs. During an operation to burst self-refresh a memory device 530, the power management controller 550 provides a signal to the memory power supply 555 indicating that power should be provided to memory

device(s) 530 or a particular memory power plane coupled to memory device(s) 530. Further, the control logic 610 (Fig. 2) of each memory device 530 will detect the conditions indicating that a refresh operation should occur. The control logic 610 (Fig. 2) provides a reset signal pulse to the refresh counter 605 and begins performing refresh operations.

[0039] The refresh counter 605 provides addresses for refresh operation of memory array 620 (Fig. 2) through address multiplexor 630 (Fig. 2) and is incremented after receiving the appropriate clock signal from control logic 610. When the refresh operation is completed, memory device 530 provides its 'refresh complete' signal by releasing its line 551 (Fig. 3). If memory device 530 is the last memory devices 530 to complete a refresh operation or if only one memory device 530 is being refreshed, line 551 returns to Vdd3, providing a refresh complete signal to I/O port 650. When the power management controller 550 receives the refresh complete signal through I/O port 650, the power management controller 550 returns the memory devices 530 and power supply 555 to the power-off state.

[0040] A memory system in a higher power setting does not require burst self-refresh and may be refreshed through conventional refresh cycles as understood by those with skill in the art.

[0041] Power management circuit 550 differs from conventional power management circuits in that power management circuit 550 receives a refresh complete signal that indicates when all the memory devices 530 have completed refreshing their respective memory arrays 620. In one embodiment, a refresh complete signal is received through I/O ports 650. Although referred to as a single signal, the refresh complete signal received can be at least two different voltages signifying different statuses. A first signal indicates that a refresh operation has been completed (i.e., 'refresh complete' signal) and the second signal indicates that a refresh operation in

progress has not been completed (i.e., 'refresh not complete' signal). Systems with multiple memory planes may have a refresh complete signal for each memory plane.

[0042] Power management circuit 550 also differs from conventional power management circuits in that the microcontroller 680 is programmed to respond to the dynamic input of the refresh complete signal. Rather than waiting a pre-determined time period to return the memory to its state prior to initiating the memory refresh operation, microcontroller 680 waits until it receives a refresh complete signal and then returns the memory to its state prior to initiating the memory refresh operation. Thus, the memory system responds dynamically to the completion of a memory refresh operation and can reduce the amount of time between the completion of a memory refresh operation and the return of the memory to its state prior to initiating the memory refresh operation. This is desirable because it allows a non-static time for the refresh operation as may be required due to the nature of the NNV memory technology, and can reduce wasted time by reducing or eliminating time delay after completion of a refresh operation before power management is initiated.

[0043] In another exemplary embodiment of the present invention, the initiation of a refresh operation is done dynamically. Fig. 5 depicts the power management controller 850. Similar to power management controller 550 (Fig. 4), power management controller 850 includes a microcontroller 880, bus 640, I/O ports 650, ROM 660, RAM 670, and inter IC (I<sup>2</sup>C) interface 690. Further, power management controller 850 includes a temperature integrator 892 and may include optional internal and external temperature sensors 893, 894.

[0044] Power management circuit 850 differs from power management circuit 550 in that the microcontroller 880 is programmed to respond to the input of the temperature integrator 892. In addition to other events that cause a burst self-refresh operation to occur in the memory device 530, microcontroller 880 is adapted to

receive a signal from the temperature integrator 892 indicating that a burst self-refresh operation should occur. In other words, microcontroller 880 dynamically determines frequency of burst self-refresh operations, based on factors such as ambient or internal temperature or other conditions occurring during memory system operation.

[0045] Temperature integrator 892 provides a signal indicating that a burst self-refresh operation should occur based on predetermined criteria. In an aspect of the exemplary embodiment of the invention, the temperature integrator 892 receives temperature sensor signals from an internal temperature sensor 893, an external temperature sensor 894, or both an internal and external temperature sensor 893, 894. An external temperature sensor 894 is located off of the memory device 530 and measures the ambient temperature conditions. An internal temperature sensor 893 is located on the memory device 530 and measures the temperature conditions within the memory device 530. In another embodiment the internal temperature sensor 893 is incorporated into the memory device 530. In another embodiment, the temperature sensor 893 integrated into the power management control.

[0046] Temperature may affect different NNV memory differently; hence, each NNV memory may require a memory refresh operation at a different temperature based on the effects of temperature on memory elements. In one embodiment, the temperature integrator 892 is preprogrammed to require differing rates of refresh operation at predetermined temperatures, e.g., trip points measured by one of the temperature sensors 893, 894. For example, when one of the temperature sensors 893, 894 indicates 80 degrees Celsius, then the temperature integrator 892 provides a signal to the microcontroller 880 that refresh operations should be initiated at a different rate than for temperatures below 80 degrees Celsius. Similarly, in another embodiment, the temperature integrator 892 is preprogrammed to require a refresh operation based on predetermined values of the integration of temperatures and times spent at each

temperature. The programming also incorporates the time since the last refresh operation occurred. In either embodiment, the chemistry of the memory cells affects the required frequency of refreshing. For example, a first type of memory having a first memory cell chemistry may need to be refreshed more often and starting at a lower temperature than a second type of memory having a second memory cell chemistry. Although described with reference to temperatures, other conditions can be monitored to initiate refresh operations. For example, ambient humidity can be monitored and trip points established at which refresh is monitored.

[0047] Fig. 6 depicts a memory system 510, such as described in connection with Figs. 1-5, included on an integrated circuit (IC) substrate 1210 to form a complete System-On-a-Chip (SOC) device. The IC 1210 includes CPU 511 with a cache, ROM 520, Bus 514, I/O devices 515, 516, and memory system 510. The resulting IC 1210 may be developed to perform a specific function or a wide range of programmable functions. IC 1210 may be incorporated into a processor system or stand-alone as a complete system.

[0048] Fig. 7 shows system 2000, a typical processor based system modified to include a NNV memory system having burst self-refresh capabilities 510. Processor based systems exemplify systems of digital circuits that could include and benefit greatly from such a memory device. System 2000 includes central processing unit (CPU) 2010, system controller 559, AGP graphics device 2015, CD ROM drive 2030, hard disk 20220, ROM 2012, I/O controller 2011, RAM 2060, NNV memory 509, power management controller 550, I/O devices 2050, 2051, and Voltage regulators Vreg2 2025, Vreg3 2026. CPU 2010, such as an Intel™ Pentium-4™, Centurion™ or XScale™ processor, that communicate directly or indirectly with various devices over bus 2070. Input/output (I/O) devices 2050 and 2051 and other devices provide communication into and out of system 2000. Other devices provide memory,

illustratively including an optional dynamic random access memory (RAM) 2060, and one or more peripheral storage devices such as hard disk drive 2020 and compact disk (CD) ROM drive 2030. This system also includes one or more instances of NNV memory 530.

[0049] While the invention has been described in detail in connection with preferred embodiments known at the time, it should be readily understood that the invention is not limited to the disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. For example, although the invention has been described in connection with specific circuits that dynamically OR refresh complete signals, the invention may be practiced with many other configurations without departing from the spirit and scope of the inventions, such as keeping refresh complete signals separate or by combining them in other ways, such as dynamic Ending or daisy-chaining. Accordingly, the invention is not limited by the foregoing description or drawings, but is only limited by the scope of the appended claims.